



Healthcare Delivery Aboard US Navy Hospital Ships Following Earthquake Disasters: Implications for Future Disaster Relief Missions

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Healthcare delivery aboard US Navy hospital ships following earthquake disasters: Implications for future disaster relief missions

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Abstract

Objective: Since 2004, the US Navy has provided ship-borne medical assistance during three earthquake disasters. Because Navy ship deployment for disaster relief (DR) is a recent development, formal guidelines for equipping and staffing medical operations do not yet exist. The goal of this study was to inform operational planning and resource allocation for future earthquake DR missions by 1) reporting the type and volume of patient presentations, medical staff, and surgical services and 2) providing a comparative analysis of the current medical and surgical capabilities of a hospital ship and a casualty receiving and treatment ship (CRTS).

Design: The following three earthquake DR operations were reviewed retrospectively: 1) USNS *Mercy* to Indonesia in 2004, 2) USNS *Mercy* to Indonesia in 2005, and 3) USNS *Comfort*/USS *Bataan* to Haiti in 2010. (The USS *Bataan* was a CRTS.) Mission records and surgical logs were analyzed. Descriptive and statistical analysis was performed. Comparative analysis of hospital ship and CRTS platforms was made based on firsthand observations.

Results: For the three missions, 986 patient encounters were documented. Of 1,204 diagnoses, 80 percent were disaster-related injuries, more than half of which were extremity trauma. Aboard hospital ships, healthcare staff provided advanced (Echelon III) care for disaster-related injuries and various nondisaster-related conditions. Aboard the CRTS, staff provided basic (Echelon II) care for disaster-related injuries.

Conclusions: Our data indicate that musculoskeletal extremity injuries in sex- and age-diverse

populations comprised the majority of clinical diagnoses. Current capabilities and surgical staffing of hospital ships and CRTS platforms influenced their respective DR operations, including the volume and types of surgical care delivered.

Key words: hospital ship, US Navy, earthquake, CRTS, disaster relief

Introduction

The US Navy provides disaster relief (DR) using hospital ships and multirole amphibious ships configured as casualty receiving and treatment ships (CRTSs; Figures 1A and 1B).^{1,2} Hospital ships (ie, USNS *Mercy*, USNS *Comfort*) are purposely built afloat medical treatment facilities that offer diagnostic and treatment capabilities equivalent to land-based tertiary care centers in the United States.³ On a smaller scale, a CRTS (eg, USS *Bataan*) is a faster, shallower-draft amphibious vessel also capable of facilitating casualty flow and providing medical and surgical care.⁴ Both ship types are capable of traveling great distances to conduct prolonged and self-sustained medical operations worldwide.

From 2004 to 2010, US Navy hospital ships were deployed in response to mass-casualty events following three earthquake disasters: the Indian Ocean 9.3-magnitude earthquake and tsunami off the Indonesian coast in 2004; the Sumatran 8.6-magnitude earthquake in 2005; and the Haitian 7.0-magnitude earthquake in 2010. The Haitian response was augmented by the amphibious ship *Bataan*, configured as a CRTS. Within days of each earthquake, these ships were equipped and en route to the affected regions. Depending on each

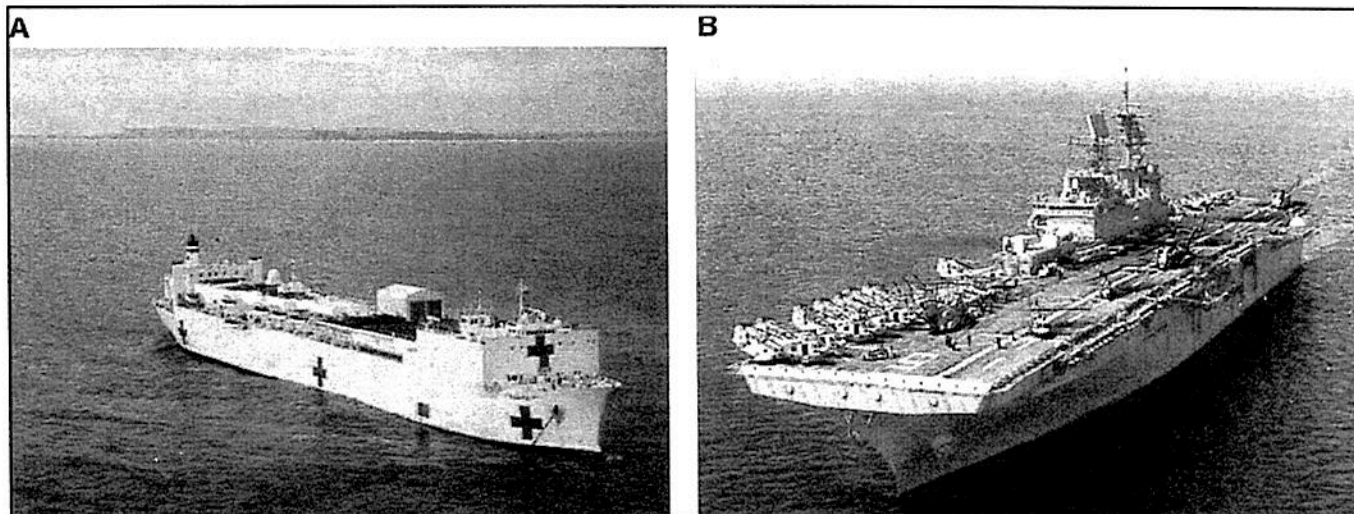


Figure 1. The US Navy provides disaster relief using hospital ships and multirole amphibious ships configured as casualty receiving and treatment ships. (A) The USNS Comfort hospital ship is a floating medical treatment facility that offers diagnostic and treatment capabilities equivalent to land-based tertiary care centers in the United States. (B) The USS Bataan is a faster, shallower-draft amphibious vessel. When properly augmented with health-care personnel, this platform is also capable of facilitating casualty flow and providing medical and surgical care.

earthquake's location, ship arrival times ranged from a few days to several weeks after the event. At each disaster site, ships were positioned offshore, in proximity to populations with the greatest need for medical assistance. By the time Navy ships arrived at these different sites, many local, foreign, civilian, and/or military organizations were already well-established ashore in either field hospitals or local treatment facilities. As a result, the hospital ships and the CRTS functioned in support of the healthcare facilities already in place. Medical DR operations were predominantly ship based to augment host nation treatment facilities and to maximize the use of each platform's unique hospital resources.^{5,6} Patients were routinely identified for admission by host nation officials or local healthcare providers, triaged by forward military teams ashore, and transported to the ship via helicopter and/or air-cushioned landing craft. Aboard the CRTS, patients were managed by a military medical crew. Aboard hospital ships, patients were managed by military medical crew augmented by civilian volunteers.^{7,8} All missions were surgically intensive. When care aboard ship was completed, collaboration between each ship's medical crew and the respective host nation healthcare providers was essential to coordinate the continued care and follow-up of all patients after discharge.

Because the use of Navy ships for DR is a relatively recent development, formal guidelines for equipping and staffing to support such medical operations do not yet exist. Presently, protocols for planning such hospital ship and CRTS operations are modeled on those used for combat casualty care, not humanitarian assistance (HA) or DR.^{9,10} To increase efficacy and decrease cost, more precise protocols are needed.^{11,12} The goal of this study was to provide knowledge essential to inform operational planning and resource allocation for future medical DR missions by 1) reporting the type and volume of patient presentations, medical staff usage, and surgical services delivered and 2) providing a comparative analysis of the medical and surgical capabilities currently embodied in a hospital ship and a CRTS.

Methods

Data from three military DR operations form the basis of this report. Official medical records and mission reports from two hospital ships (*Mercy* in 2005, *Comfort* in 2010) and one CRTS (*Bataan* in 2010) were analyzed to determine patient demographics, preoperative diagnoses, surgical procedures performed, and surgical specialties used. For all operations, the patient logs detailing surgical treatments provided the most comprehensive and complete patient-encounter data. Descriptive

analysis was performed to summarize data sets. When hospital ship or CRTS data were incomplete, additional information was gathered from mission participants.

Medical capabilities currently embodied in the US Navy hospital ship and CRTS are outlined, and a comparative analysis of how each platform was used during DR is made based on firsthand observations during the three missions. Lessons learned are offered.

Results

Overview

Logs documented a total of 986 patients treated aboard US Navy ships during three DR missions. For these patients, 1,204 diagnoses were recorded, 1,109 of which were assigned a medical/surgical specialist as a primary care provider. Not all surgical procedures were consistently or comprehensively recorded for all missions. Of the surgical treatments that were well documented, 540 patients received 1,126 surgical procedures. Preliminary statistical analysis showed that the distributions of diagnoses and procedures for disaster-related and nondisaster-related patients were significantly different ($p = 0.001$). Further statistical inference was limited due to small sample sizes, particularly by the small number of disaster-related patients in the Indonesian operations.

Individual operations

Event: Indian Ocean 9.3-magnitude earthquake and tsunami, 2004.

Hospital ship: USNS *Mercy*

Mission: Operation Unified Assistance I (OUA I)

Location: Banda Aceh, Indonesia

On December 26, 2004, a 9.3-magnitude, undersea earthquake occurred off the west coast of Banda Aceh, Indonesia, with an epicenter ~160 miles southwest of the city of Banda Aceh. This was the second-most powerful earthquake recorded since 1900. The resulting massive tsunami swept across the Indian Ocean, devastating coastal regions in more than a dozen nations. The western coastal area of Sumatra, including Banda Aceh, was the area most devastated. Although estimates vary, in the Aceh province ~200,000 people were killed by the

earthquake and tsunami, about 500,000 were displaced, and tens of thousands suffered illness and/or injury.^{13,14}

On January 5, 2005, *Mercy* departed from San Diego, CA, en route to the earthquake- and tsunami-devastated region of Sumatra, Indonesia. Total transit time across the Pacific and Indian Oceans was 1 month. Upon arrival off the coast of Banda Aceh, *Mercy* joined an ongoing international DR effort. Serving primarily as an offshore referral center, hospital operations began on February 7, 2005, and ended 35 days later on March 14.

Mercy crew documented surgical treatment of 137 patients, 72 percent of whom were patients with nondisaster-related conditions, 26 percent with disaster-related conditions, and 2 percent with unspecified conditions (Figure 2). Age and sex data were not available for all patients, only those with disaster-related surgical conditions. The majority of such patients were adults (ie, 95 percent aged 17-60 years), and the elderly

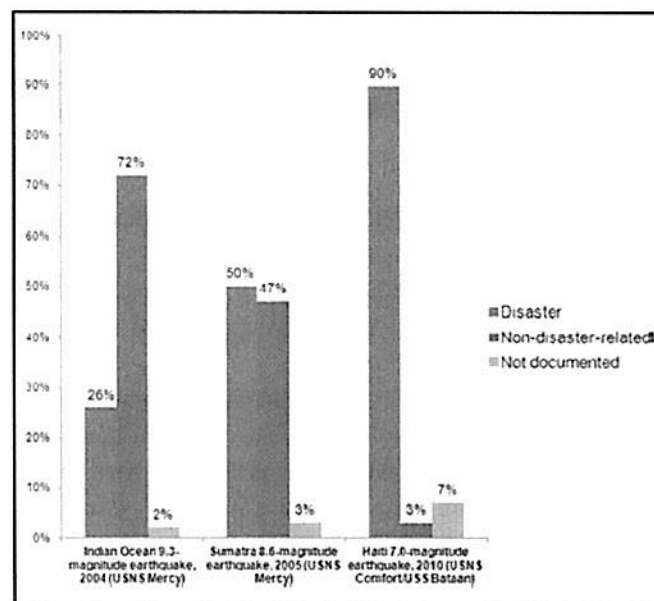


Figure 2. Of the patients aboard USNS *Mercy* after the Indian Ocean 9.3-magnitude earthquake and tsunami off the Indonesian coast in 2004, most were treated for nondisaster-related conditions. Aboard *Mercy* after the Sumatran 8.6-magnitude earthquake, approximately half the patients were treated for disaster-related conditions and half were treated for nondisaster-related conditions. After the Haitian 7.0-magnitude earthquake, most patients were treated for disaster-related conditions aboard USS *Bataan* and USNS *Comfort*.

(aged >61 years) comprised the remainder. No children (<17 years of age) with disaster-related conditions were treated with surgery aboard ship during this mission. The most common preoperative diagnoses were tumor (29 percent), fracture (19 percent), gastrointestinal condition/disease (12 percent), eye condition/disease (9 percent), disease not otherwise specified (NOS; 9 percent), genitourinary condition/disease (8 percent), burn injury (4 percent), and open wound/soft-tissue injury (4 percent). For all patients, 203 surgical procedures were recorded, the most common of which were biopsy/tumor excision (17 percent), incision and drainage (I&D) of wound (14 percent), internal fixation of fracture (11 percent), treatment for gastrointestinal conditions (eg, hernia and fistula repair, appendicitis; 10 percent), and treatment for genitourinary conditions (eg, renal or bladder stones; 9 percent). Accordingly, a wide variety of specialists were used to manage the cases: general surgery (30 percent), otolaryngology/oral maxillofacial surgery (ENT/OMFS; 16 percent), orthopedics (16 percent), interventional radiology (14 percent), ophthalmology (10 percent), urology (8 percent), obstetrics/gynecology (OB/GYN; 4 percent), and plastic surgery (3 percent).

Event: Sumatra 8.6-magnitude earthquake, 2005.

Hospital ship: USNS *Mercy*

Mission: Operation Unified Assistance II (OUA II)

Location: Nias, Indonesia

On March 28, 2005, an 8.6-magnitude undersea earthquake occurred off the west coast of Sumatra, Indonesia, with an epicenter approximately halfway between the islands of Nias and Simeulue.¹⁵ Nias was hit the hardest, with a death toll estimated at greater than 1,000 people. In the island's largest city of Gunungsitoli, hundreds of buildings were destroyed and tens of thousands of people were displaced.¹⁶ Two days later, *Mercy* redeployed from nearby East Timor to Nias. Total transit time across the Indian Ocean was 5 days. After arrival, HA and DR operations began on April 5, 2005, and ended 25 days later on April 30.

Mercy crew documented surgical treatment of 72 patients, approximately half of which were for disaster-related conditions. As with the previous mission records,

age and sex data were only available for patients with disaster-related surgical conditions. Of these patients, two-thirds were adults, nearly a third were children, while older patients comprised the smallest age demographic. The most common diagnoses were fracture (22 percent), tumor (20 percent), open wound/soft-tissue injury (18 percent), eye condition/disease (12 percent), disease NOS (9 percent), burn injury (5 percent), genitourinary condition/disease (5 percent), traumatic amputation/unsalvageable extremity (2 percent), and head injury (2 percent). For all patients, 136 surgical procedures were recorded. The most common procedures were I&D of wound (38 percent), internal fixation of fracture (10 percent), biopsy/tumor excision (9 percent), treatment for ophthalmologic problems (8 percent), vascular surgery/procedure (5 percent), exploratory laparotomy (4 percent), treatment for genitourinary conditions (4 percent), and soft-tissue coverage of wound (4 percent). Again, a wide variety of specialists primarily managed these cases: orthopedics (28 percent), general surgery (22 percent), interventional radiology (14 percent), ophthalmology (13 percent), ENT/OMFS (7 percent), and OB/GYN (7 percent).

Event: Haitian 7.0-magnitude earthquake, 2010.

Hospital ship: USNS *Comfort*

Casualty receiving treatment ship: USS *Bataan*

Mission: Operation Unified Response

Location: Grand Goâve and Port-au-Prince, Haiti

On January 12, 2010, a 7.0-magnitude earthquake occurred, with an epicenter ~15 miles southwest of Port-au-Prince, Haiti. This was the most powerful Haitian earthquake on record since 1770. Although estimates vary, ~222,000 people were killed, 300,000 injured, and 1.3 million displaced in the Port-au-Prince area and much of southern Haiti.¹⁷

On January 14, *Bataan* deployed from Norfolk, VA, en route to the earthquake-devastated region of Grand Goâve, Haiti. Total transit time to Haiti was 4 days, which included a stopover in Camp Lejeune, NC, to pick up ~2,000 US Marines. On January 16, *Comfort* deployed from Baltimore, MD, en route to Port au Prince, Haiti. Total transit time was also 4 days.

Aboard *Bataan*, casualty receiving and treatment began on January 18, and ended on February 12, 2010. *Bataan* crew documented surgical treatment of 47 patients (87 percent disaster-related). Although most surgical patients were adults (72 percent), a substantial number of children were treated (21 percent), while the elderly comprised the minority of patients (7 percent). Most patients presented with fracture (41 percent), open wound/soft-tissue injury (39 percent), or traumatic amputation/unsalvageable extremity (8 percent). The 109 surgical procedures performed included I&D of wound (63 percent), closed reduction of joint or fracture under anesthesia (13 percent), internal fixation of fracture (6 percent), external fixation of fracture (6 percent), vascular surgery/procedure (4 percent), and amputation (3 percent). Surgical specialties used to primarily manage the majority of cases included orthopedics (55 percent), general surgery (29 percent), ENT/OMFS (15 percent), and OB/GYN (2 percent).

Aboard *Comfort*, casualty receiving and treatment began on January 19 and ended on March 10, 2010. There were 730 patient encounters recorded and available for analysis, 90 percent of which were documented to have disaster-related conditions. Notably, 20 percent of patients had multiple diagnoses. Similar to the *Bataan* experience, most surgical patients were adults (69 percent), nearly one-third were children (26 percent), and the elderly again comprised the minority (5 percent). The overwhelming majority of patients were treated for fracture (45 percent). Other common diagnoses included open wound/soft-tissue injury (10 percent), head injury (7 percent), spinal injury (5 percent), and traumatic amputation/unsalvageable extremity injury (4 percent). The most common treatments included I&D of wound (46 percent), internal fixation of fractures (14 percent), external fixation of fractures (9 percent), soft-tissue coverage of wounds (5 percent), and amputation (5 percent). Surgical specialties used to primarily manage the majority of cases included orthopedics (55 percent), general surgery (9 percent), neurosurgery (8 percent), internal medicine (6 percent), spinal surgery (4 percent), OB/GYN (4 percent), ENT/OMFS (3 percent), ophthalmology (3 percent), and plastic surgery (1 percent).

Table 1. Disaster-related diagnoses

Diagnosis (n = 768 patients*)	N	Percent
Fracture	478	49.5
Open wound/soft-tissue injury	127	13.2
Head injury	83	8.6
Amputation	50	5.2
Trauma, NOS	47	4.9
Spinal injury	43	4.5
Burn	31	3.2
Disease, NOS	25	2.6
Pregnancy/postpartum state	8	0.8
Other/not recorded	73	7.6
Total	965	100.0
Abbreviation: NOS, not otherwise specified. *Ninety-one percent Haiti and 9 percent Indonesia.		

All operations summary results

Patient diagnoses encountered aboard hospital ships. Disaster-related diagnoses (n = 965) were available for 768 patients treated during three military DR operations in Indonesia and Haiti (Table 1). For all missions, fracture was the most common disaster-related diagnosis (49.5 percent). The anatomical locations for fracture injuries were upper/lower extremities (17.0 percent/63.6 percent), pelvis (12.8 percent), and maxillofacial (5.8 percent). Although mission data are incomplete, a substantial number of the fractures were open injuries, associated with complex and/or contaminated soft-tissue wounds (eg, surgeons treating Haitian nationals aboard *Bataan* documented 55 percent of extremity fractures as open). The second most common disaster-related diagnosis was soft-tissue injury/open wound (13.2 percent). By anatomical location, upper/lower extremities were most often involved (21.1 percent/54.2 percent). The third most common diagnostic group included patients with head trauma (8.6 percent) who typically had a constellation of complex injuries and, therefore, multiple diagnoses

Table 2. Nondisaster-related diagnoses		
Diagnosis (n = 155 patients*)	N	Percent
Tumor/mass/growth	59	35.1
Eye disease/disorder	22	13.1
Gastrointestinal condition/disease	19	11.3
Genitourinary condition/disease	17	10.1
Disease, NOS	15	8.9
Open wound/soft-tissue injury	10	6.0
Burn	6	3.6
Other/NOS	20	11.9
Total	168	100.0
Abbreviation: NOS, not otherwise specified.		
*Eighty-six percent Indonesia and 14 percent Haiti.		

(eg, traumatic brain injury, skull fracture, maxillofacial fracture, and eye trauma). The fourth most common diagnostic group included patients presenting with traumatic amputation/unsalvageable extremity injuries (5.2 percent). Among these patients, the lower extremity was involved nearly three times more often than the upper extremity. The fifth most common group included patients with unspecified trauma/polytrauma to chest, abdomen, and/or extremities (4.9 percent). The remaining most common diagnostic groups included patients with spinal injury, burn injury, systemic diseases, and pregnancy/postpartum state.

Nondisaster-related diagnoses (n = 168) were available for 155 patients treated during operations in Indonesia and Haiti (Table 2). The most common nondisaster-related diagnosis was tumor/mass/or growth (35.1 percent). The second most common diagnosis was for atraumatic conditions of the eye (13.1 percent), with cataract disease making up the majority of these cases (71.4 percent). The third most common diagnostic group included patients with conditions/diseases of the gastrointestinal tract (11.3 percent), such as cholecystitis, appendicitis, and hernia. The fourth most common nondisaster-related diagnostic group included patients with conditions/diseases of the genitourinary

tract (10.1 percent), such as nephrolithiasis, cystolithiasis, and fistulae.

Diagnoses that were not clearly documented as either disaster-related or nondisaster-related (n = 71) were recorded for 63 patients. For this cohort, the most common diagnoses were pregnancy/postpartum state (28.2 percent), disease NOS (26.8 percent), spinal injury (8.5 percent), gastrointestinal condition/disease (7.0 percent), and open wound/soft-tissue injury (5.6 percent).

Medical specialties used. There were 1,109 medical/surgical specialty assignments available for review (Table 3). A substantial number of patients required care from multiple different medical specialists, especially those patients with disaster-related, polytraumatic conditions. For patients with disaster-related conditions (n = 871), orthopedic surgery (59.2 percent) was the most commonly used specialty, followed by general surgery (10.4 percent), neurosurgery (6.9 percent), ENT/OMFS (4.6 percent), spinal surgery (4.0 percent), internal medicine (2.8 percent), and ophthalmology (2.5 percent). For the 170 patients with nondisaster-related conditions, the most commonly used specialty was general surgery (38.8 percent), followed by ophthalmology (14.7 percent), ENT/OMFS (11.8 percent), interventional radiology (11.2 percent), urology (8.2 percent), OB/GYN (7.6 percent), neurosurgery (2.4 percent), and orthopedic surgery (1.8 percent). For patients with diagnoses that were not clearly classified as disaster-related or nondisaster-related, OB/GYN was the most commonly used specialty (33.8 percent), followed by internal medicine (30.9 percent), neurosurgery (7.4 percent), interventional radiology (5.9 percent), general surgery (4.4 percent), orthopedic surgery (4.4 percent), and ophthalmology (1.5 percent).

Surgical procedures performed. There were 906 surgical procedures documented for 382 of the patients with disaster-related conditions (Table 4). A substantial number of these patients presented with multiple injuries and required multiple surgical procedures. The most common surgical procedures performed included I&D of wound (48.2 percent), internal fixation of fracture (22.2 percent), external fixation of fracture (7.2 percent), soft-tissue procedure

Table 3. Medical/surgical specialty usage					
Specialty	Patients*		Percent of patients with disaster-related diagnosis (n = 871)	Percent of patients with nondisaster-related diagnosis (n = 170)	Percent of patients with diagnostic status not recorded (n = 68)
	N	Percent			
Orthopedics	522	47.1	59.2	1.8	4.4
General surgery	160	14.4	10.4	38.8	4.4
Neurosurgery	69	6.2	6.9	2.4	7.4
ENT/OMFS	60	5.4	4.6	11.8	0.0
Ophthalmology	48	4.3	2.5	14.7	1.5
OB/GYN	48	4.3	1.4	7.6	33.8
Internal medicine	47	4.2	2.8	1.2	30.9
Interventional radiology	38	3.4	1.7	11.2	5.9
Spinal surgery	35	3.2	4.0	0.0	0.0
Plastic surgery	16	1.4	1.6	1.2	0.0
Urology	15	1.4	0.1	8.2	0.0
NOS	51	4.6	4.7	1.2	11.8
Abbreviations: ENT/OMFS, otolaryngology/oral maxillofacial surgery; NOS, not otherwise specified; and OB/GYN, obstetrics/gynecology. *Total of 1,109 patients using specialists (80 percent Haiti and 20 percent Indonesia).					

to close/cover wounds (5.5 percent), amputation (4.6 percent), closed reduction of joint or extremity fracture (3.2 percent), vascular surgery/procedure (2.4 percent), ophthalmologic procedure (1.0 percent), and craniotomy (1.0 percent). There were 203 surgical procedures documented for 142 of the patients with nondisaster-related conditions (Table 5). The most common surgical procedures performed included biopsy/tumor excision (21.7 percent), gastrointestinal surgery/procedure (13.3 percent), ophthalmologic procedure/eye surgery (12.8 percent), genitourinary surgery/procedure (11.3 percent), and I&D of wound (10.3 percent). Diagnoses were not clearly classified as disaster-related or nondisaster-related for a small minority of patients (n = 15) who underwent surgical

procedures. Of this minority, birth was the most commonly recorded procedure aboard ship.

Demographic characteristics of patients

For all missions, most patients with disaster-related conditions were of adult age (17-60 years), while the elderly (61 years and older) consistently comprised a smaller, but sizeable, demographic. For two of the three missions (Sumatra and Haiti), nearly a third of patients were children (<1-16 years). The most complete mission data detailing age and sex information for patients with disaster-related conditions was obtained from the *Comfort* mission to Port-au-Prince, Haiti. For this mission, the age distribution for 715 patients was as follows: adults (69.1 percent), infants

Table 4. Surgical procedures for patients with disaster-related diagnosis

Procedure category*	Percent of total procedures	Percent of patients with procedure (n = 382)
Incision & drainage of wound	48.2	56.3
Internal fixation of fracture	22.2	45.3
Internal fixation of fracture: extremity	14.8	31.4
Internal fixation of fracture: spine	3.2	7.1
Internal fixation of fracture: maxillofacial	1.8	4.2
Internal fixation of fracture: pelvis	1.7	3.9
Internal fixation of fracture: NOS	0.8	1.6
External fixation (application, modification, and removal)	7.2	15.2
Skin graft/soft-tissue flap	5.5	12.3
Amputation	4.6	10.5
Closed reduction: joint or fracture	3.2	7.3
Vascular: surgery/procedure	2.4	5.0
Ophthalmology procedure/eye surgery	1.0	2.4
Craniotomy	0.9	2.1
Facial reconstruction	0.9	1.8
Other/NOS	3.9	8.6
Total	100.0	—
Abbreviation: NOS, not otherwise specified.		
*Eighty-four percent Haiti and 16 percent Indonesia.		

and children (25.9 percent), and the elderly (4.9 percent). Sex information recorded for adults demonstrated that two-thirds of the patients were female.

The hospital ship and the CRTS: Medical capability during DR

Hospital ship. Medical capabilities of US Navy hospital ships are substantial and second only to fleet hospitals ashore. These ships are 894 ft (272.5 m) in length, offer a 1,000-bed capacity, including an 80-bed intensive care unit (ICU), 12 operating rooms (ORs), and a 20-bed recovery ward. Departments and facilities include casualty reception, radiographic services

(including a computed tomography [CT] scanner, an angiography suite, echocardiography, Doppler ultrasound, two fluoroscopy suites, and multiple portable C-arm fluoroscopy units), central sterile receiving, biomedical repair, pharmacy, physical therapy, burn care, dental services, optometry services/lens laboratory, histopathology, full laboratory, and blood bank services.

To date, initial surgical staffing of hospital ships for DR missions has been determined according to the established combat casualty care model. For example, when *Mercy* deployed to the earthquake- and tsunami-devastated region of Banda Aceh, Indonesia, surgical team members included orthopedic surgery (two), OB/GYN

Table 5. Surgical procedures for patients with nondisaster-related diagnosis		
Procedure category	Percent of total procedures	Percent of patients with procedure (n = 142)
Biopsy/tumor excision	21.7	28.9
Gastrointestinal surgery/procedure	13.3	17.6
Ophthalmology procedure/eye surgery	12.8	17.6
Genitourinary surgery/procedure	11.3	9.9
Incision & drainage of wound	10.3	10.6
Vascular: surgery/procedure	5.9	7.7
Hysterectomy ± salpingo-oophorectomy	4.4	6.3
ENT/OMFS: misc. procedure	3.4	5.6
Escharotomy/fasciotomy	3.4	4.2
Exploratory laparotomy	2.5	3.5
Other/not specified	10.8	13.3
Total	100.0	—
Abbreviation: ENT/OMFS, otolaryngology/oral maxillofacial surgery. *Eight percent Haiti and 92 percent Indonesia.		

(two), head and neck surgery (one), oral/maxillofacial surgery (one), general and burn surgery (four), vascular surgery (one), urology (one), dental surgery (two), and plastic surgery (one). Anesthesia support initially included a team of anesthesiologists (three) and one registered nurse anesthetist. However, during this mission and all subsequent DR missions using hospital ships, mission requirements dictated that additional staff be added after the ship arrived in theater. Thus, for all missions in Indonesia and Haiti, critical surgical specialties such as orthopedics, neurosurgery, and anesthesiology were augmented post hoc by additional military personnel or by civilian volunteers from various nongovernmental organizations (NGOs) (eg, Project HOPE, Orthopedic Trauma Association [OTA]) to meet mission goals.

For most patients with disaster-related injuries in Indonesia and Haiti, definitive treatment aboard the hospital ships was made possible through the tertiary care capabilities as well as the availability of a wide range of military and rotating civilian medical and

surgical specialists. Likewise, a substantial number of patients with a wide array of nondisaster-related conditions also received comprehensive care.

Casualty receiving treatment ship. A CRTS is a general purpose amphibious assault ship that, when properly augmented with healthcare personnel, provides emergency life- and limb-saving treatment to casualties inside or very close to the theater of military operations. Medical and surgical capabilities of a CRTS are more limited relative to that of a hospital ship. The CRTS offers a smaller casualty receiving/triage area, 6 ORs, 17 ICU beds; 47 ward beds; 540 overflow beds; basic laboratory services (eg, complete blood count, chemistry panel, type and cross), blood bank, pharmacy, dental services, sterile receiving, biomedical repair, and basic radiological services (including digital X-ray suite, portable X-ray, and ultrasound).¹⁸

Similar to Navy hospital ships, CRTS medical staffing has previously been based on a combat

casualty care model. For example, when *Bataan* deployed to earthquake-devastated region of Grand Goâve, Haiti, surgical staffing included general surgery (three surgeons), orthopedic surgery (two), OB/GYN (one), oral/maxillofacial surgery (one). Anesthesia support included a team of anesthesiologists (three) and one registered nurse anesthetist who could routinely support four ORs per day. Unlike the hospital ship missions to Haiti and Indonesia, no additional military or civilian medical staff were added during the course of the deployment.

During Operation Unified Response, the CRTS and crew provided patients with basic imaging and laboratory diagnostic services, primary medical and wound care, and damage-control surgery (eg, I&D of wounds, closed reduction of fractures/dislocations under anesthesia, external fixation of fractures, and amputation). Despite adequate staffing with expertise to manage patients with disaster-related conditions and injuries, the platform's lack of fluoroscopy and the very limited supply of orthopedic equipment and implants disallowed definitive surgical management of most extremity fractures, including all long-bone fractures. Accordingly, many patients with extremity injuries were only provisionally managed aboard the CRTS (eg, fluid resuscitation, traction, I&D, and external fixation) before subsequent transfer to *Comfort* for definitive care (eg, intramedullary nailing of long bone and flap coverage of wound).

Discussion

According to the mission data from the three earthquake-relief missions using US Navy ships, complex musculoskeletal injuries comprised the overwhelming majority of disaster-related conditions encountered and treated. Patient presentations during these missions may not be representative of disaster presentations as a whole, but they are very likely to be highly representative of presentations on US Navy ships. By definition, US Navy ships are largely self-sufficient, operate remotely from disaster recovery operations ashore, contain substantial command and control capabilities, and provide a secure environment where medical care can be provided. As a result, triage on shore rightly assigns the most care intensive and

severely injured patients to the most intact and disaster independent-care-providing facility: ship-borne medical treatment facilities.

US Navy hospital ships and missions of DR: The need for guidelines to manage civilian mass casualties

US Navy ship-borne medical treatment facilities, whether a hospital ship or CRTS, are manned and equipped for the primary purpose of treating battle-inflicted trauma for a demographic of healthy Americans aged 18-53 years. These platforms are capable of providing substantial medical assistance during DR operations without equipment, supply, and personnel augmentation, but they are not currently ideally configured to care for civilian populations impacted by an earthquake or other type of disaster. As a result, there have been inefficiencies, such as reconfiguration of medical staff after arrival in theater, ad hoc purchasing of medical specialty equipment and supplies, and transport and admission of patients whose care requirements exceeded available resources (eg, patients with long-bone fractures brought aboard a CRTS). More precise guidelines for staffing and equipping US Navy CRTS and hospital ships for earthquake-related disasters are therefore indicated.

To plan the most effective medical and surgical response to an earthquake disaster using Navy ships, mission requirements knowledge is critical and must include insight into the type and complexity of injuries and conditions on shore, the volume of patients likely to require treatment, the at-risk population demographics, and the basic medical and surgical skill sets required to accomplish the mission. After three ship-borne earthquake-relief missions to Indonesia and Haiti, a consistent pattern of injuries and care requirements has been documented by US Navy medical crews. These clinical data afford an opportunity to better match personnel and equipment to expected medical needs following an earthquake or tsunami and may therefore facilitate operational planning based on predicted clinical tasks.^{19,20}

Disaster-related diagnoses and medical specialty requirements

For the earthquakes in Indonesia and Haiti, extremity fractures comprised the predominant

disaster-related condition encountered aboard Navy ships. Of the extremity fractures, approximately two-thirds involved the lower extremity and half were complicated by soft-tissue injury (eg, open fracture). These findings are consistent with those documented in previous earthquake-related injury studies.²¹⁻²⁵ Although patients with simple extremity injuries and urgent amputations could be addressed quickly by local or early-arriving healthcare providers on shore, patients with more severely injured extremities could not be effectively or definitively treated until a more sophisticated facility, such as *Mercy* or *Comfort*, was available. Although the time of each ship's arrival to locations in Indonesia and Haiti influenced the acuity of injuries seen, it did not significantly alter the proportion of disaster-related musculoskeletal injuries seen.

For patients with disaster-related conditions, orthopedic surgery was the most frequently used specialty (59 percent), and surgical treatment of bone and soft-tissue extremity injuries accounted for more than two-thirds of the total surgical caseload. The remaining procedures, in order of frequency, involved general surgery, neurosurgery, ENT/OMFS, and spinal surgery. Plastic surgery (2 percent) would have been used with greater frequency had there been a consistent presence of plastic surgeons with expertise in soft-tissue coverage procedures (eg, free and rotational flaps and skin grafting). Thus, to maximize mission effectiveness, medical crew staffing for earthquake mass-casualty disasters should reflect the specific skill sets most critical to these events. This should include the confirmation of specific abilities and experience of medical personnel beyond their surgical subspecialty designation (eg, an orthopedic or general surgeon with fellowship training and active clinical practice in trauma, a plastic surgeon with a expertise in rotational and free-flap wound coverage, an anesthesiologist with expertise in regional anesthesia).²⁶

Notably, the inclusion of civilian medical professionals has served to expand the capacities of the Navy medical crew in providing DR.²⁷ In an era of severe strain on military medical resources, the inclusion of civilian personnel from NGOs and medical professional societies (eg, Project HOPE and OTA) as

medical colleagues and force multipliers has proved extremely successful and should continue.

Nondisaster-related diagnoses and medical specialty requirements

Because each earthquake disaster disrupted the local healthcare infrastructure, a subset of patients with acute and/or chronic nondisaster-related conditions presented for treatment aboard the ships. The ratio of disaster-related to nondisaster-related conditions was also influenced by delay in arrival of the ship as well as the time length of the mission.²⁸

For patients with nondisaster-related conditions, diagnoses and medical needs differed significantly from the disaster-related population. The most common conditions encountered were tumors, pregnancy/postpartum conditions, eye disorders, gastrointestinal and genitourinary problems, followed by a variety of disease, and injuries typically seen in any emergency room or urgent-care facility. Medical specialties most often required to manage these patients were general surgery, OB/GYN, internal medicine, interventional radiology, ophthalmology, ENT/OMFS, and urology. To the extent that mission planning is to accommodate the care of nondisaster-related conditions, medical staffing must include these specialties. Given the wide range of nontraumatic problems documented, there is added value in selecting medical staff with more diverse clinical experience rather than highly specialized expertise in a relatively narrow medical subspecialty field. However, certain subspecialty expertise is of particular value in DR missions (eg, infectious disease).²⁹

Patient demographics: Implications for managing civilians aboard military ships

Depending on the mission, up to one-third of surgical patients were children and the elderly. The notable exception to this trend was aboard *Mercy* in the earthquake- and tsunami-affected region of Banda Aceh, Indonesia, where none of the surgeries performed for disaster-related injuries involved children. This experience may reflect the reality that tsunami mortality rates were highest among the youngest members of the Indonesian population.³⁰

Pediatric and elderly patients have unique physiological and psychological attributes that make them particularly vulnerable after a natural disaster.^{31,32} Problematically, medical personnel and resources routinely aboard a US Navy CRTS or hospital ship are primarily based on protocols for providing care to military units ashore and afloat, and the demographic of active-duty military personnel is at considerable variance from the demographics of emerging countries affected by an earthquake. Accordingly, medical and surgical care of the very young or very old aboard Navy ships after a disaster has been challenging and has often required unusual measures (eg, recycling pediatric endotracheal tubes and manufacturing ambulatory assistive devices). Future mission planning requires attention to provide clinical expertise and specialty equipment necessary to adequately address the needs of these patients.

Surgical patient volumes: Implications for improving access to care

According to the patient logs available for this study, the numbers of individuals with well-documented encounters were 137 patients aboard *Mercy* (Banda Aceh, Indonesia), 72 patients aboard *Mercy* (Nias, Indonesia), and 777 patients aboard *Bataan* and *Comfort* (Grand Goâve and Port au Prince, Haiti). However, these numbers represent only a fraction of the number of patients impacted by disaster and who might have benefited from hospital ship or CRTS resources. Our experience has shown that a critical rate-limiting factor in treating disaster victims aboard these ships has not been the availability of medical expertise, particularly when staffing was augmented with civilian healthcare professionals. Rather, what most often limited the ability to bring more patients aboard were the number of helicopters and landing craft available for transport of patients; the number of beds, ORs, or ICU bays that were activated for use; the number of nurses available to care for patients; and the duration of each ship's stay in theater.^{33,34}

The hospital ship and the CRTS: Medical capability during DR

Although both the hospital ship and CRTS platforms provided surge capacity to shore-based healthcare facilities in Indonesia and Haiti, there were

substantial differences in the medical DR operations. Regarding patient volume, because CRTS facilities (versus hospital ships) are less robust in terms of ward and ICU bed space and OR availability, the number of patients accepted for inpatient care was far less than that documented aboard *Mercy* and *Comfort* during their respective missions. In terms of the services provided, orthopedic care aboard the CRTS (vs hospital ships) was much more challenging due to limited radiology assets (eg, a single X-ray suite, a single portable X-ray machine, no CT scanner, and no fluoroscopy).³⁵ Likewise, orthopedic surgery was less often definitive due to lack of a standard supply of equipment and implants necessary to treat most of the musculoskeletal injuries encountered (eg, no fracture table, orthopedic implants limited to two Hoffmann External Fixation sets and one Synthes Small Fragment Set).³⁶

Conclusion

From 2004 to 2010, US Navy hospital ships arriving in the aftermath of three earthquake disasters in Indonesia and Haiti provided surge capacity to field hospitals and shore-based healthcare facilities. These missions have been internationally recognized and reflect the dedication of the Navy and the United States to providing on-site sophisticated medical care that would be otherwise unavailable. Our data show that musculoskeletal extremity injuries in a sex- and age-diverse population comprised the majority of clinical problems encountered. Current capabilities and surgical staffing of hospital ships and CRTS platforms influenced their respective medical DR operations, particularly in terms of the volume and type of surgical care delivered.

It is important to emphasize the impact of time delay associated with deploying Navy ships to remote regions in response to natural disasters. For the missions analyzed, the time elapsed between each earthquake and the arrival of a Navy hospital ship or CRTS ranged from several days to several weeks. According to our data, early versus late arrival times substantially influenced DR medical operations in terms of the acuity of injuries, the ratio of disaster to nondisaster cases, and the patient demographics (eg, number of pediatric cases).

It is also important to emphasize that a sea-based response to earthquake disasters using a Navy hospital

ship or CRTS is not suggested as a surrogate for shore-based facilities or field hospitals. Rather, our data suggest that these specialized ships may augment healthcare facilities on shore by offering additional and/or advanced medical and surgical services in a secure, self-sustaining hospital environment offshore. This study not only highlights many medical capabilities of the CRTS and hospital ships but also underscores the current limitations inherent in ship-borne DR operations. Although our analysis may inform medical planning and staffing, it should be coupled with a similar analysis of helicopter usage and nursing capacity, as our experience has shown that these are the factors limiting the number of patients receiving treatment. We have refrained from recommending any absolute numbers of particular medical specialists needed because these would derive from the numbers of ORs, postoperative care beds, and helicopter transports that would be made available. Surgical and medical staff numbers could likely be ramped up as needed and on short notice (eg, augmentation by civilian resources) as accomplished aboard *Comfort* following the 2010 Haitian earthquake.

In conclusion, on the basis of the data in this report, a staffing and resource template may be developed to better match the anticipated needs during earthquake DR missions, especially in terms of surgical expertise, manpower, and supplies. Ultimately, patient-specific models for surgical subspecialty staffing and supplying of future hospital ship missions may be developed to accomplish predicted clinical tasks following an earthquake disaster.

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14. ABSTRACT <p>Since 2005, the US Navy has provided ship-borne medical assistance during three earthquake disasters. Because Navy ship deployment for disaster relief (DR) is a recent development, formal guidelines for equipping and staffing medical operations do not yet exist. The goal of this study was to inform operational planning and resource allocation for future earthquake DR missions by (1) reporting the type and volume of patient presentations, medical staff, and surgical services; and (2) providing a comparative analysis of the current medical and surgical capabilities in a hospital ship and a casualty receiving and treatment ship (CRTS). Three earthquake DR operations were reviewed retrospectively: (1) USNS <i>Mercy</i> to Indonesia in 2004, (2) <i>Mercy</i> to Indonesia in 2005, and (3) USNS <i>Comfort</i>/USS <i>Bataan</i> to Haiti in 2010. For three missions, 986 patient-encounters were documented. Of 1,204 diagnoses, 80% were disaster-related injuries, over half of which were extremity trauma. Aboard hospital ships, health care staff provided advanced (Echelon III) care for disaster-related injuries and various non-disaster-related conditions. Aboard the CRTS, staff provided basic (Echelon II) care for disaster-related injuries. Our data show that musculoskeletal extremity injuries in sex- and age-diverse populations comprised the majority of clinical diagnoses. Current capabilities and surgical staffing of hospital ships and CRTS platforms influenced their respective DR operations, including the volume and types of surgical care delivered.</p>					
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